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"SIMMER Code Improvements and Applications in Safety Analysis of MYRRHA Reactor"

RELATORI

Prof. Ing. *Walter Ambrosini*
DICI

Dott. Ing. *Nicola Forgione*
DICI

IL CANDIDATO

Simone Gianfelici

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Abstract

As a part of collaboration between the Dipartimento di Ingegneria Civile ed Industriale (DICI) of the University of Pisa and the Institut für Kern- und Energietechnik (IKET) of the Karlsruher Institut für Technologie, a FORTRAN program, for the restarting of calculations for SIMMER III code was developed. The “SIMMER-to-SIMMER coupling program” gives great flexibility in comparison with the default RESTART capability of the code and allows modifying any option in the input file.

The first part of this thesis work describes the SIMMER-III code and the ADS reactors, in particular the MYRRHA-FASTEF reactor.

In the fourth chapter a description of the coupling program and the 2D domain adopted in the description of the MYRRHA reactor is presented. The results of a 500 s steady-state calculation are compared with those of a standard RESTART and of a restart carried out with the coupling program, both from 200 s of simulation. For both restarts, pressure and velocities are in good agreement with the steady-state analysis, while the temperatures show small differences during the two transients.

The coupling program was used to start transients of fuel release, equivalent to the mass of fuel present in a single pin, in natural and forced circulation. The results are then compared to those already obtained by DICI, started with velocity and temperature fields chosen by the user and with radius of fuel particles equal to 1 mm. Due to the different velocity and temperature fields at the beginning of the transients, a higher amount of fuel particles was calculated in proximity of the baffle in forced circulation conditions. Furthermore, for natural circulation calculations, the fuel particles released tend to concentrate more in proximity of the free level of the hot pool. According to the results of the SEARCH meetings, the radius was then set to 75 micrometers and a comparison with the previous simulation is reported. The smaller fuel particles tend to float and accumulate more, in particular in the regions where the coolant has low velocities.

Finally, to check the coherence of the geometry approximations of the 2D mesh, the results of the last analysis are compared with those of the analyses of fuel pin release performed with the 3D model of MYRRHA developed by DICI and ENEA. Differently from the 2D one, the 3D domain shows high concentration of fuel particles between the diaphragm and the vessel, and a lower amount in the pumps and the cold pool A certain amount of fuel near the baffle is anyhow predicted.

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Nomenclature

Acronyms

ADS	Accelerator Driven System
AFDM	Advanced Fluid-Dynamics Model
BoC	Beginning of Cycle
BoL	Beginning of Life
CAD	Computer-Aided Design
CDA	Core Disruptive Accident
CDT	Central Design Team
CEA	Commissariat A L'energie Atomique
CFD	Computational Fluid-Dynamic
CP	Continuous Phase
CPU	Central Processor Unit
CR	Control Rod
CRGT	Control Rod Guide Tube
CSS	Core Support Structure
DA	Dummy Assembly
DBC	Design Basis Condition
DHR	Decay Heat Removal
DICI	Dipartimento di Ingegneria Civile ed Industriale of University of Pisa
DPIN	Detailed Fuel-Pin Model
EFIT	European Facility for Industrial Transmutation
ENEA	Agenzia nazionale per le nuove tecnologie, l’energia e lo sviluppo economico sostenibile

EoC	End of Cycle
EoL	End of Life
EOS	Equation Of State
ETD	European Transmutation Demonstration
FA	Fuel Assembly
FASTEF	Fast Spectrum Transmutation Experimental Facility
FC	Forced Circulation
FZK	Forschungszentrum Karlsruhe
GFR	Gas Fast Reactor
GIF	Generation IV International Forum
HLM	High Liquid Metal
HMT	Heat and Mass Transfer model
HTC	Heat Transfer Coefficient
IAEA	International Atomic Energy Agency
IFA	InterFacial Area model
IKET	Institut für Kern- und Energietechnik
IPS	In-Pile Section
IVFHM	In-Vessel Fuel Handling Machine
IVFS	In-Vessel Fuel Storage
JNC	Japan Nuclear Cycle Development Institute
KIT	Karlsruhe Institute of Technology
LANL	Los Alamos National Laboratory
LBE	Lead-Bismuth Eutectic
LFR	Lead Fast Reactor

LMFR	Liquid Metal Fast Reactor
LWR	Light Water Reactor
M/F	Melting/Freezing
MA	Minor Actinide
MFBT	Minimum Film Boiling Temperature
MFC	Multi-Functional Channel
MOX	Mixed OXide fuel
MRK	Modified Redlich-Kwong
MSR	Molten Salt Reactor
MWC	Melt Water Contact
MYRRHA	Multi-purpose hYbrid Research Reactor for High-tech Applications
NC	Natural Circulation
P&T	Partitioning & Transmutation
PBA	Protected Blockage Accident
PDS-XADS	Preliminary Design Studies of an eXperimental Accelerator Driven System
PHX	Primary Heat eXchanger
PNC	Power Reactor and Nuclear Fuel Development Corp
PTOP	Protected Transient OverPower
RVACS	Reactor Vault Air Cooling System
R&D	Research & Development
RIA	Reactivity Induced Accident
RV	Reactor Vessel
SA	Sub-Assembly
SAEOS	Simplified Analytic EOS

SCARA	Selective Compliant Assembly (Articulated) Robot Arm
SCRAM	Safety Control Rod Axe Man
SCWR	Super Critical Water Reactor
SEARCH	Safe ExploitAtion Related CHemistry for HLM reactors
SFR	Sodium Fast Reactor
SG	Steam Generator
S-S	Steady-State
SR	Safety Rod
SS	Stainless Steel
SPIN	Simplified Fuel-Pin Model
TRU	TRansUranium element
V/C	Vaporization/Condensation
VHTR	Very High Temperature Reactor
VF	Volume Fraction
WP	WorkPackage
XS	eXtenSion (SIMMER)
XT-ADS	eXperimental Transmuter and irradiation facility based on ADS concept

Roman Letters

A	interfacial area (m^{-1})
a	binary-contact area per unit volume (m^{-1})
ALPGK	volume fraction of gas
ALPLK4	volume fraction of fuel particles
ALPLK5	volume fraction of clad particles

C_{ORF}	orifice coefficient
c	heat capacity (J/kg/K)
D_h	hydraulic diameter (m)
E	entrainment
e	specific internal energy (J/kg)
f	volume fraction
g	gravity (m/s^2)
Gr	Grashof number
H	heaviside unit function
h	heat transfer coefficient (W/m^2/K)
i	specific enthalpy (J/kg)
K	inter-field momentum exchange function (kg/m^3/s)
L	characteristic length (m)
Nu	Nusselt number
p	pressure (Pa)
Pr	Prandtl number
Q	heat transfer rate (W/m^3)
q	heat transfer rate (W/m^3)
R	gas constant (J/kg/K)
r	radius (m)
Ra	Rayleigh number
Re	Reynolds number
S	interfacial area source term (1/m/s)
T	temperature (K)

TLK3	LBE temperature (°C)
TIPINK	center pin temperature (°C)
TSK1	surface pin temperature (°C)
TSK4	clad temperature (°C)
TSK8	can wall temperature (°C
v	specific volume of the structure
$\vec{V}$	velocity (m/s)
$\vec{v}$	velocity (m/s)
$\overrightarrow{VM}$	virtual mass ($kg/m^2/s^2$)
We	Weber number

Greek letters

α	volume fraction or void fraction
δ	thermal penetration length (m)
Γ	mass-transfer rate per unit volume ($kg/s/m^3$)
κ	thermal conductivity (W/m/K)
μ	dynamic viscosity (Pa·s)
ρ	density (kg/m^3)
$\overline{\rho}$	macroscopic density (kg/m^3)
σ	surface tension (N/m)
τ	time constant (s)

Subscripts

a	fuel pin interior node
B	bubbly flow regime

b	fuel pin surface node
c	cladding or continuous phase
CP	continuous phase
Crt	critical (temperature)
D	dispersed flow regime
d	dispersed phase
f	fuel
$film$	film region
FS	liquid film
G	vapour mixture
GL	Terms existing at interface between vapour and liquid velocity
G_m	energy component m in a vapour field
hb	fluid and fuel pellet surface (rate of energy interchange between)
hc	fluid and cladding (rate of energy interchange between)
HT	heat transfer
int	fuel pin interior node
L	liquid component
LCW	left can wall
L_m	energy component m in a liquid field
M	material number or energy component
m	density component
MF	melting/freezing (rate of energy interchange due to)
N	nuclear (heating rate)
nf	non-flow volume

P	particle component
PIN	fuel pin
$pool$	pool flow regime
q, q'	velocity fields
qq'	terms existing at interface between two velocity fields
RCW	right can wall
S	Structure component
$slug$	slug flow regime
S_m	energy component m in a structure
str	structure
VC	vaporization/condensation (rate of energy interchange due to)
VS	vapour structure

Superscripts

I	interface quantity